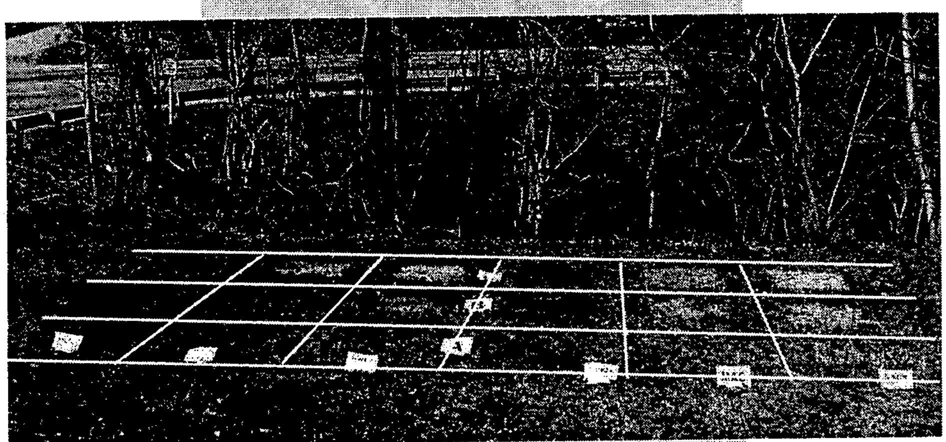
FINAL REPORT

PB2000-103289

EVALUATION OF AN ICE BAN® PRODUCT AS A PREWETTING AGENT FOR SNOW REMOVAL AND ICE CONTROL OPERATIONS



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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Transportation Research Council
(A Cooperative Organization Sponsored by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

January 2000
VTRC 00-R12

Standard Title Page - Report on Federally Funded Project

1. Report No. FHWA/VTRC 00-R12	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of an Ice Ban® Product as a Prewetting Agent for Snow Removal and Ice Control Operations		5. Report Date January 2000 6. Performing Organization Code
7. Author(s) Daniel S. Roosevelt and G. Michael Fitch		8. Performing Organization Report No. VTRC 00-R12
9. Performing Organization and Address Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 00021703
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	FHWA 400 North 8th Street, Room 750 Richmond, VA 23239	13. Type of Report and Period Covered Final 11/97-10/99 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The purpose of this project was to determine if the Virginia Department of Transportation (VDOT) should use Ice Ban M50 for snow and ice control. Ice Ban M50 was evaluated for its effects on snow removal and ice control operations, the environment, and the highway infrastructure. The operational component consisted of a literature review. The environmental component consisted of tests conducted on roadside vegetation, turfgrass seed, and freshwater minnows. The highway infrastructure component consisted of tests conducted on concrete and metals.

The researchers concluded that the cost and operational problems associated with using Ice Ban M50 as a prewetting agent exceeded those associated with using $MgCl_2$ as a prewetting agent. VDOT should consider experimentation in which Ice Ban M50 is applied directly to pavements when temperatures are below −12 °C. Experimentation should proceed cautiously until additional research addresses concerns with product stability, mold, and other probable environmental issues.

17 Key Words		18. Distribution Statement	
Ice Ban, snow removal, ice control, winter maintenance, environmental effects of chemicals		No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 21	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ABSTRACT

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INTRODUCTION

The Virginia Department of Transportation (VDOT) currently uses deicing techniques for snow removal and ice control at most locations. *Deicing* consists of removing snow and ice after it has bonded to the pavement. Anti-icing techniques, primarily the technique of prewetting, are used at other locations. *Anti-icing* consists of preventing snow and ice from bonding to the pavement by the timely application of a chemical freezing-point depressant. *Prewetting* is defined as spraying a liquid freezing-point depressant on a granular material before placing it on the road. The granular material is primarily sodium chloride (NaCl), and the prewetting usually occurs as the material leaves the spreader.

Ice Ban® (Ice Ban) is the registered trade name of a group of agricultural by-products patented for use as roadway deicing/anti-icing agents. The products are produced and distributed in liquid form. Technical data sheets published by Ice Ban America, Inc. (1997), the patent holder for Ice Ban products, indicate that Ice Ban products contain agricultural by-products such as stillage, grain processors' condensed solubles, steepwater (condensed corn processing steep liquor), brewers condensed solubles, vintners condensed solubles, and whey. Much of the product is used as animal food and is biodegradable.

Preliminary tests indicate that Ice Ban products work well as freezing-point depressants and corrosion inhibitors and are environmentally benign when compared to chemicals traditionally used in snow removal and ice control. The patent holder claims additional benefits from use of the product, such as reduced salt usage and a residual effect during subsequent storms (Banasiak, 1997).

Ice Ban is applied either directly to the roadway or as a prewetting agent to granular salt. In concentrated form, its freezing point is approximately –18°C, but the material becomes viscous below 0 °C. For this reason, Ice Ban is usually mixed with other chemicals to form a less viscous liquid before being used for snow removal and ice control. These mixtures are marketed under many names, such as Ice Ban Magic, Ice Ban Plus, and Ice Ban M50. The Ice Ban product most readily available in Virginia is Ice Ban M50, which is a mixture of 50% Ice Ban concentrate and 50% magnesium chloride ($MgCl_2$) brine. The $MgCl_2$ brine is 30% $MgCl_2$ and 70% water.

Ice Ban is more expensive than traditional anti-icing and deicing chemicals. In 1997, the price for Ice Ban in Virginia was \$0.33/L (\$1.25/gal). The prices for more traditional anti-icing chemicals, converted to liquid measure, were \$0.015/L (\$0.06/gal) for NaCl, \$0.17/L (\$0.65/gal) for $MgCl_2$, and \$0.13/L (\$0.50/gal) for calcium chloride ($CaCl_2$). Based only on cost, it appears that Ice Ban cannot compete with the more traditional chemicals. However, if Ice Ban products can reduce corrosion of equipment, infrastructure damage, and the adverse environmental effects of traditional chemicals while maintaining the level of service provided by current anti-icing techniques, its use may be cost-effective.

PURPOSE AND SCOPE

The purpose of this project was to determine if VDOT should use Ice Ban M50 for snow and ice control. The objectives were to evaluate Ice Ban M50 in three areas:

1. its effect on VDOT's snow removal and ice control operations
2. its effects on the environment
3. its effect on the highway infrastructure.

This study primarily evaluated Ice Ban M50 as a prewetting agent for NaCl and compared the results with those for NaCl alone and/or NaCl prewetted with $MgCl_2$. In some cases, laboratory tests included samples of Ice Ban M50 and $MgCl_2$.

The operational component of the study was to consist of comparing the use of NaCl prewetted with Ice Ban M50 (test section) and NaCl prewetted with $MgCl_2$ (control section) in anti-icing operations during winter storms. The field trials were scheduled for the winter seasons of 1997-98 and 1998-99. No significant snow event occurred during the 1997-98 winter season, and only one occurred during the 1998-99 winter season. For this event, the trucks assigned to the test section were contract vehicles, equipped with chemical spreaders and prewetting equipment (saddle tanks). Prior to the snow event, the saddle tanks were filled with $CaCl_2$. Although the $CaCl_2$ was removed, the tanks were not flushed prior to the introduction of Ice Ban M50. As a result, a precipitate formed that clogged the filters and nozzles of the spray system. The anti-icing equipment was, thus, unusable during the storm, and no data on the effect of the Ice Ban M50 were collected for this study.

The environmental component of this study consisted of tests conducted on roadside vegetation, turfgrass seed, and freshwater minnows. Each test was designed to compare the effects of NaCl treated with Ice Ban M50 and the effects of untreated NaCl. No tests examining the long-term effects of NaCl treated with Ice Ban M50 were conducted.

The highway infrastructure component of this study consisted of tests conducted on concrete and metals. The tests were designed to evaluate the long-term scaling effects on concrete surfaces and the corrosive effects on metals. The tests compared the effects of NaCl prewetted with Ice Ban M50 to the effects of untreated NaCl and to the effects of NaCl treated with $MgCl_2$.

METHODOLOGY

Literature Review

A search was made of the TRANSPORT database, via Silver Platter, for relevant studies completed or started since 1988. In addition, investigators in other ongoing research efforts were contacted.

Environmental Effects

Three tests were conducted to estimate the effects of Ice Ban M50 on the environment: a turfgrass seed germination test, an acute toxicity test for fathead minnows, and a roadside vegetation stress test.

Turfgrass Seed Germination Test

The effects of five deicing chemicals on *Rebel II* turfgrass seeds were determined in accordance with SHRP H-205.11 (Strategic Highway Research Program, 1992) and EPA/560/6-82/002 (U.S. Environmental Protection Agency, 1982).

The initial test concentrations of the chemicals ranged from 100% to 1% of the eutectic composition of NaCl and $MgCl_2$ in distilled water (23% and 22% by mass, respectively). As previously stated, 100% Ice Ban M50 is composed of 50% Ice Ban concentrate and 50% $MgCl_2$ brine. The 100% NaCl + Ice Ban M50 mixture contained 23% NaCl, 1% Ice Ban M50, and 76% distilled water. The NaCl + $MgCl_2$ mixture contained 23% NaCl, 1% $MgCl_2$, and 76% distilled water. Subsequent dilutions were made from these maximum concentrations.

Thirty seeds each were exposed to 100%, 50%, 25%, 10%, 5%, and 1% concentrations of each deicer for 5 days, and germination counts were recorded for each concentration. The radicle length of seeds that germinated was measured. The germination counts and radicle lengths were statistically analyzed using a two-tailed Fisher's exact test.

Since the initial testing indicated that germination did not occur in the presence of any of the deicing chemicals when the concentrations were greater than 10%, a second test was conducted using concentrations ranging from 1% to 10% of the eutectic concentrations. This test was conducted for NaCl and NaCl + Ice Ban M50.

Minnow Acute Toxicity Test

For this test, the procedures outlined in SHRP H-205.11 (Strategic Highway Research Program, 1992b) and EPA/600/4-90/027F (U.S. Environmental Protection Agency, 1993) were used. NaCl and Ice Ban M50 were combined at the prewetting ratio of 94% NaCl to 6% Ice Ban M50 (by mass), and the mixture was added to distilled water to test concentrations of 8, 9, 10, 11, and 12 g/L. Juvenile fathead minnows (*Pimephales promelas*), 15 to 25 mm in length, were exposed to these concentrations for 24 hours, and mortality rates and pH before and immediately following the test period were recorded. Dissolved oxygen was monitored for the first 8 hours, and the final value recorded at the end of the test. The concentration that was lethal to 50% of the test organisms (LC_{50}) for the NaCl + Ice Ban M50 solution was calculated using the Spearman-Karber method as outlined in EPA/600/4-90/027F (U.S. Environmental Protection Agency, 1993).

Roadside Vegetation Stress Test

The effects of the same five deicing chemicals on roadside vegetation were tested. Each chemical was tested in three concentrations (low, medium, and high) based on generous estimates of the amount of deicer that would infiltrate within 1 m of the edge of the pavement and application rates recommended by the Federal Highway Administration (1998) for each deicer (see Table 1).

Mixtures were diluted with distilled water to 5 L in plastic containers and poured on a 1-m^2 test plot on February 19, March 12, and March 25, 1999. Each chemical made contact with the leaves of the plants and directly infiltrated the soil matrix. Care was taken to prevent runoff from the application area.

Before the first chemical application, fluorescence and reflectance were measured for each plot using a MicroFLD prototype fluorescence detector under development for the U.S. Army Corps of Engineer, Topographic Engineering Center, and the Virginia Institute of Marine Science. This technology allows for the quantification of stress in plants by calculating the red/near infrared ratio of the relative reflectance intensity (Carter, Dell, & Cibula, 1996; Rock, Hoshizaki, & Miller, 1988; Rock, Miller, Moss, Freemantle, & Boyer, 1990; Vogelmann, Rock, & Moss, 1993). A second set of measurements was made in May 1999, following the final chemical application and spring green up of the vegetation. The before and after measurements were evaluated using the two-tailed Kolmogorov-Smirnov test for different distributions.

Table 1. Mixtures Used for Roadside Vegetation Stress Test

Deicer	Roadway Application Rate	Low	Medium	High
NaCl	70 g/lane-m	210 g	420 g	630 g
$MgCl_2$	70 g/lane-m	210 g	420 g	630 g
IB M50	0.0823 L/lane-m	250 ml	500 ml	750 ml
NaCl + IB M50	70 g NaCl + 0.003 L IB M50/lane-m	210 g + 9 ml	420 g +18 ml	630 g + 27 ml
NaCl + $MgCl_2$	70 g NaCl + 0.924 g $MgCl_2$/lane-m	210 g + 2.8 g	420 g + 5.5 g	630 g + 8.3 g
Control	NA	NA	NA	NA

Infrastructure Effects

The effect on the highway infrastructure of NaCl treated with Ice Ban M50, NaCl treated with $MgCl_2$, NaCl alone, and Ice Ban M50 alone was determined by laboratory tests. The tests compared the effect on concrete surfaces and metal. The laboratory tests followed the procedures in SHRP H-205.9 and SHRP H-205.7 (Strategic Highway Research Program, 1992a).

Concrete Scaling Test Procedure

Fifteen concrete blocks were tested in accordance with SHRP H-205.9. Three blocks each were used for testing each of the four chemical solutions. Three blocks were used as control samples and were treated with deionized water. Variations from the procedure outlined in SHRP H-205.9 were as follows:

1. The concrete had the following characteristics:
   - slump, 42 mm
   - air content, 3.8%
   - density, 2260 kg/m^3
   - compressive strength after 28 days, 24 MPa.
2. The blocks were 320 mm long by 90 mm wide by 60 mm deep with a stainless steel band around the molded reservoir.
3. Approximately 200 ml of deicing chemical and water was added to the reservoir of each block. The composition of each chemical solution is shown in Table 2. The blocks were covered with Saran Wrap, secured with rubber bands, and placed in an upright freezer at -18 ± 2 °C overnight. The blocks were subjected to 20 cycles of freezing and thawing.

At the conclusion of every 5 cycles, the surface of each block was visually rated in accordance with ASTM C 672-92. After 20 cycles, the mass of concrete lost (scaling) was determined and the samples tested with each chemical were compared with the samples treated with every other chemical, including the control.

Table 2. Deicer Chemical Solutions

Deicer Solution	Mixture (Liquid/NaCl)	% Deicer by Mass of Chemical Solution
Deionized water (control sample)	---	---
NaCl + H_2O	---	3
NaCl + $MgCl_2$ (33%) + H_2O	1 ml/30 g	3
NaCl + IB M50 + H_2O	1 ml/30 g	3
IB M50 + H_2O	---	3

Corrosion of Metal Test Procedure

Sixteen carbon steel, metal test coupons were tested in accordance with SHRP H-205.7. Three coupons each were used for testing each of the four chemical solutions. Three coupons were used as control samples and were treated with water. One sample was reserved to monitor mass loss attributable to cleaning only.

The samples were kept at room temperature hanging in 500-ml plastic beakers containing about 300 ml of test solution. The coupons were not in the solution but were very close to the surface. The beakers were covered with Plexiglas containing one hole to allow for aeration of the liquid from a small aquarium air pump. Once a week, the coupons were drenched with their respective deicer chemical solution. Because aerating the chemical solution in accordance with the procedure created so much mold in the Ice Ban M50 samples, the test procedure was modified to change the chemical solution every week instead of every 2 weeks as specified. The procedure was repeated for 6 weeks.

At the completion of the test, the corrosion rate was determined for each coupon. The corrected weight loss of each coupon is the test specimen weight loss minus the cleaning control weight loss. The corrosion rate was calculated using the following information:

$$CR \text{ (mg/yr)} = (K \bullet CWL)/(A \bullet T \bullet D)$$

where CR = corrosion rate

K = 8740, a constant to convert milligrams per hour to milligrams per year

CWL = corrected weight loss (mg)

A = specimen area (3750 mm^2)

T = time of exposure (6 wk = 989.5 h)

D = density for steel (7860 g/mm^3).

Statistical Evaluation

To evaluate the effects of each chemical tested, a statistical comparison was made between each set of samples, including the control. In each comparison, the null hypothesis (H_0) was that chemical solution 1 and chemical solution 2 cause the same amount of concrete block scaling or metal coupon corrosion. The alternate hypothesis (H_a) was that chemical solution 1 causes more scaling or corrosion than chemical solution 2. Since the primary purpose of the study was to evaluate Ice Ban M50 as a prewetting agent for NaCl, chemical solution 1, when possible, was primarily NaCl. A one-tailed Fisher's exact probability test ($\alpha = 0.1$) was used to determine if any differences in concrete scaling and the metal coupon corrosion rate were statistically significant.

FINDINGS AND DISCUSSION

Literature Review

A 1998 study by the Highway Innovative Technology Evaluation Center (HITEC, 1998), a service center of the Civil Engineering Research Foundation and the research affiliate of the American Society of Civil Engineers, provides preliminary results of laboratory tests and a summary of the experiences of state and local highway agencies with Ice Ban during the winter of 1996-97. The laboratory tests covered both Ice Ban (the concentrated product) and Ice Ban Plus, but the field experiences applied only to Ice Ban Plus. Ice Ban Plus has the same formula as Ice Ban M50. The findings included the following:

- There is considerable variability in the chemical characteristics tested.
- Based on use of the WSDOT method (Washington State Department of Transportation, 1998), Ice Ban products are less corrosive to metals than Type II distilled water, NaCl, $MgCl_2$, or corrosion-inhibited $MgCl_2$.
- Field tests involving granular NaCl, prewetted at the spinner, indicated improved performance and increased residual chemical carry over when compared with untreated NaCl in both anti-icing and deicing operations.

The report gave no indication of the authors' statistical confidence in the data upon which these findings were based.

Another preliminary report from HITEC (1999) presented additional findings for laboratory tests and field trials. The preliminary findings for laboratory tests included the following:

- The ice melting capacity and rate for Ice Ban M50 was greater than that for liquid $MgCl_2$ at all temperatures tested.
- The tests for scaling effect on the concrete mixes tested indicated that Ice Ban M50 causes less scaling than other chemicals tested ($MgCl_2$, NaCl, $CaCl_2$, potassium acetate, calcium magnesium acetate) and the control, which was distilled water.

The field trials involved 204 evaluations. Only about a dozen of the evaluations used a strictly controlled test and control procedure. There was variation in the Ice Ban product formulation, control chemical, application technique, application rate, and type of storm over the evaluation sites. Of the evaluations, 115 compared NaCl prewetted with an Ice Ban product to NaCl prewetted with $MgCl_2$ or $CaCl_2$. None of these evaluations was conducted under the strictly controlled procedure, and 113 were performed in Wisconsin. The preliminary findings from the field tests included the following:

- In field trials of Ice Ban and a number of traditional snow removal and ice control chemicals, the Ice Ban products provided equivalent or better performance in 99% of the cases.

- Wisconsin indicated that NaCl prewet with Ice Ban Plus or C50 (a mixture of 50% Ice Ban concentrate and 50% $CaCl_2$) provided equal or better deicing performance than untreated NaCl or NaCl prewet with $CaCl_2$, even when applied to the road at significantly lower rates than the standard practice.

- When applied as a direct liquid, Ice Ban products melted snow faster, at lower temperatures, and had a greater residual effect than $MgCl_2$.

The study also reported on Ice Ban products applied directly to the road surface in 23 evaluations:

- In evaluations performed in Colorado and Indiana, Ice Ban Plus melted snow and ice faster and at lower temperatures than $MgCl_2$ solution. According to field personnel in Indiana and Washington, Ice Ban Plus provided a more consistent, longer lasting residual effect (i.e., ability to reactivate between storms) than $MgCl_2$.

- In controlled field trials in New York, sprayed applications of Ice Ban Plus used in an anti-icing strategy significantly reduced the amount of NaCl needed in follow-up applications during the course of a snowstorm.

A final report by the Winter Materials and Technologies Evaluation Team of the Maryland Department of Transportation/State Highway Administration (1999) described the use of a mixture of NaCl and Ice Ban M50, which was premixed at the stockpile prior to the winter. The mixture was used in a controlled situation on three occasions over the winter of 1998-99 on roads maintained by the Montgomery County Shop. On each occasion, the mixture was used on a test section and compared with the use of untreated granular NaCl on a control section. During the first storm, the pavement temperature ranged from (-7° C down to –11° C). During the second storm, the pavement temperature ranged from (5° C down to 6° C). During the third snowstorm, the pavement temperature at the time of application was (5° C). Results were mixed.

- During the first storm, less salt was used at the Ice Ban M50 site than at the adjacent control sites, and the cost of controlling snow and ice at the Ice Ban M50 test site was 17% to 60% less, respectively, than in the two control sections.

- During the second storm, the salt treated with Ice Ban M50 never went into brine.

- During the third storm, the product never went into brine.

MDSHA and the vendor undertook laboratory tests of the product after the second storm but at the time of publication had reached no conclusion regarding the variation in the product's performance. A conversation with one of the researchers (M. Lipnick, personal communication, August 5, 1999) revealed that a stockpile of NaCl mixed with Ice Ban M50 had drawn a large rodent population over the winter. The rodents dug tunnels in the stockpile and appeared to be eating the material. The stockpile was located at their Washington County Shop near Hagerstown.

Taken as a whole, the three reports and the technical data from Ice Ban America, Inc. (1997) indicated two particular tendencies:

1. There was considerable variability in the composition and performance of the product from use to use even when taken from the same stockpile.

2. In cases where Ice Ban products were used as a prewetting liquid for NaCl and improved performance, the comparison was usually made to untreated NaCl.

Environmental Effects

Turfgrass Seed Germination Test

Test 1

Table 3 provides the results of the first turfgrass seed germination test. Figure 1 compares the germination counts of turfgrass seeds exposed to deicers at the 5% concentration. The use of both Ice Ban M50 and NaCl + Ice Ban M50 resulted in significantly lower germination counts compared with all other deicers at this concentration. There was no

Table 3. Seed Germination Counts for Test 1

Chemical Concentration (%)	Control	NaCl	$MgCl_2$	IB M50	NaCl + IB M50	NaCl + $MgCl_2$
100	23/30	0/30	0/30	0/30	0/30	0/30
50		0/30	0/30	0/30	0/30	0/30
25		0/30	0/30	0/30	0/30	0/30
10		0/30	0/30	0/30	0/30	0/30
5		26/30	19/30	1/30	6/30	24/30
1		25/30	26/30	26/30	24/30	29/30

5% Concentration alpha = 0.05	NaCl	$MgCl_2$	NaCl + $MgCl_2$	NaCl + IB M50	IB M50
Control	*	*	*	←	←
IB M50	↑	↑	↑	*	
NaCl + IB M50	↑	↑	↑		
NaCl + $MgCl_2$	*	*			
$MgCl_2$	*				

* No statistical difference

Figure 1. Matrix for Test 1 Showing Results of Two-Tailed Fisher's Exact Test Comparing Germination Counts of Turfgrass Seeds Exposed to Deicers at 5% Concentration. Arrows point to deicer that yielded the statistically higher germination count.

statistical difference in the germination counts at the 1% concentration. This may have been due to the formation of mold in the Petri dishes, which did not occur with any other deicer (see Figure 2). Both samples had considerable mold on the filter paper medium and on the seeds themselves.

Figure 3 shows the average radicle lengths for seeds that germinated. Figure 4 compares the radicle lengths of turfgrass seeds exposed to deicers at the 5% and 1% concentrations.

At the 5% concentration, there was insufficient germination of the Ice Ban M50 samples to conduct a statistical analysis of the radicle lengths. The use of NaCl + Ice Ban M50 resulted in significantly lower radicle lengths compared with all other deicers at this concentration. Again, this may have been due to the formation of mold in the Petri dishes.

Figure 2. Mold in Seed Germination Dishes Containing Ice Ban M50

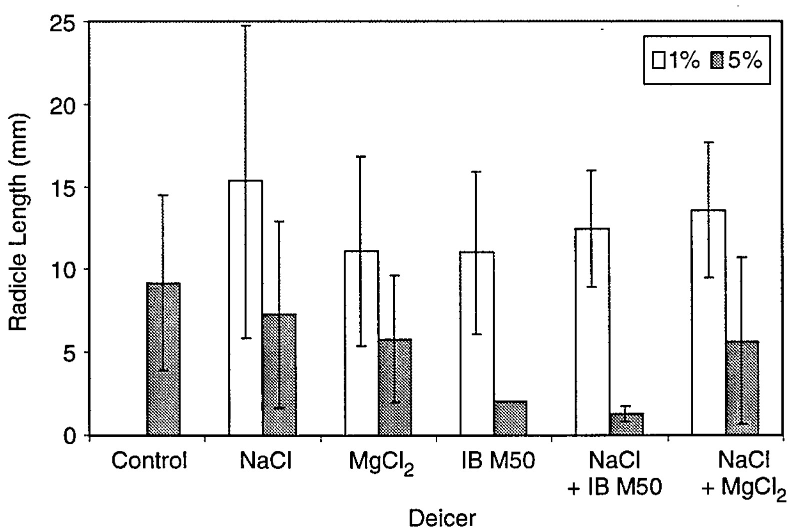

Figure 3. Average Radicle Length with Deicers at 5% and 1% Concentrations for Test 1

5% Concentration alpha = 0.05	NaCl	$MgCl_2$	NaCl + $MgCl_2$	NaCl + IB M50	IB M50
Control	*	←	←	←	NA
IB M50	NA	NA	NA	NA	
NaCl + IB M50	↑	↑	↑		
NaCl + $MgCl_2$	*	*			
$MgCl_2$	*				

1% Concentration alpha = 0.05	NaCl	$MgCl_2$	NaCl + $MgCl_2$	NaCl + IB M50	IB M50
Control	*	*	↑	*	*
IB M50	*	*	↑	*	
NaCl + IB M50	↑	←	*		
NaCl + $MgCl_2$	*	*			
$MgCl_2$	*				

* No statistical difference

Figure 4. Matrix Showing Results of Two-Tailed Fisher's Exact Test Comparing Radicle Lengths of Turfgrass Seeds Exposed to Deicers at 5% and 1% Concentrations for Test 1. Arrows point to deicer that yielded the statistically longer radicle length. NA = not applicable because of insufficient samples.

At the 1% concentration, the statistical analysis of the radicle lengths showed no pattern. The average radicle length of each deicer sample was greater than that of the control. This combined with the germination count results indicates that at low concentrations, the deicers tested had no negative effects on radicle length. In addition, no mold was observed in any sample at this concentration.

Test 2

Table 4 shows the results of the second test comparing germination counts for seeds exposed to NaCl and NaCl + Ice Ban M50. Figure 5 shows the average radicle lengths for seeds that germinated. The germination count for NaCl + Ice Ban M50 was higher than in the first test.

Table 4. Seed Germination Counts for Test 2

Concentration (%)	NaCl	NaCl + IB M50
9	0/30	0/30
8	0/30	0/30
7	0/30	0/30
6	9/30	6/30
5	10/30	17/30
4	22/30	19/30
3	26/30	21/30
2	27/30	26/30
1	26/30	28/30

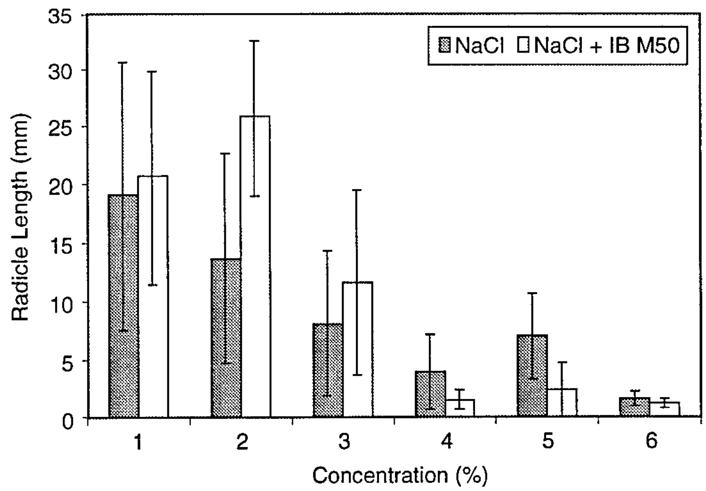

Figure 5. Average Radicle Length with NaCl and NaCl + Ice Ban M50 for Test 2

There was no statistical difference between the germination counts of seeds exposed to NaCl and those exposed to NaCl + Ice Ban M50. The statistical results for the radicle lengths were mixed. Radicle lengths were not statistically different at the 1%, 3%, and 6% concentrations. Turfgrass seeds exposed to NaCl + Ice Ban M50 had a greater average radicle length at the 2% concentration. The use of NaCl resulted in a longer radicle length with the 4% and 5% concentrations.

Mold was not present in any sample. This supports the premise that the presence of mold in the samples containing Ice Ban M50 in Test 1 negatively affected the germination counts. The researchers were told by the manufacturer that the Ice Ban M50 used for both tests did not contain the mold inhibitor that is normally a part of the Ice Ban M50 mix.

Minnow Acute Toxicity Test

Figure 6 shows the mortality rates for the fathead minnow acute toxicity test. The results were plotted with results of previous tests done with NaCl as indicated in SHRP H-205.11 (Strategic Highway Research Program, 1992b). LC_{50} was 9.75 g/L for NaCl + Ice Ban M50 and 9.79 g/L for NaCl, which are similar.

It was not the intent of the researchers to determine the effects of Ice Ban M50 on water quality parameters, but pH and dissolved oxygen data were collected as a part of this test. Figure 7 shows the final values for pH and dissolved oxygen for the NaCl + Ice Ban M50 solutions and for NaCl as taken from SHRP H-205.11 (Strategic Highway Research Program, 1992b). The pH values dropped from nearly 7.5 in the control to 5.8 for the 12 mg/L concentration at the conclusion of the 24-hour test. This differs significantly from the SHRP data where pH values remained above 7 for all concentrations of NaCl. The greatest difference between the two tests, however, was the values for dissolved oxygen. There was a significant drop in the dissolved oxygen values for the higher concentrations of NaCl + Ice Ban M50 that was not evident with

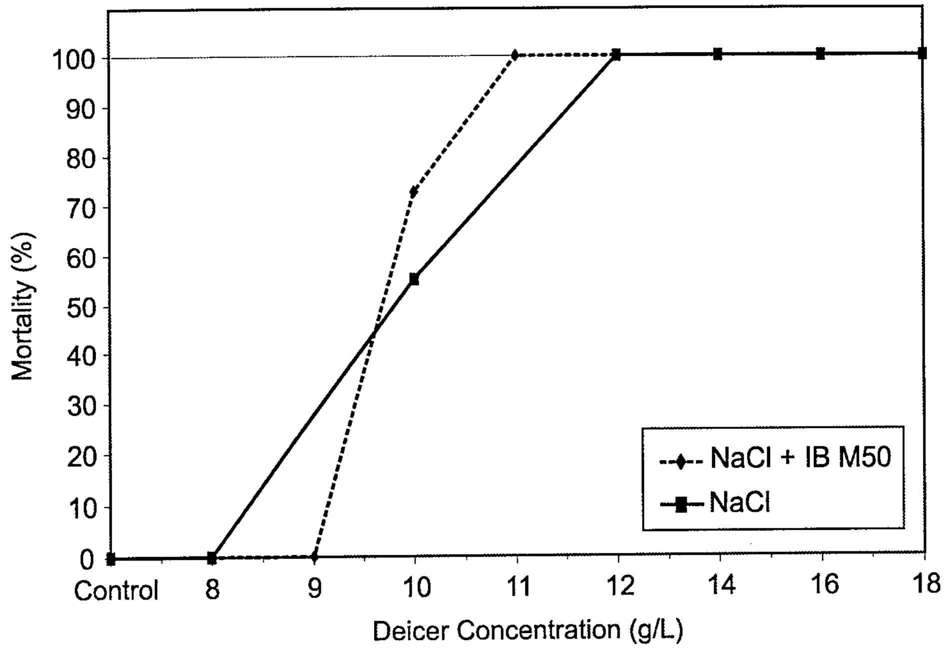

Figure 6. Mortality Rates of Fathead Minnows During Acute Toxicity Test. NaCl values were taken from SHRP H-205.11 (Strategic Highway Research Program, 1992b).

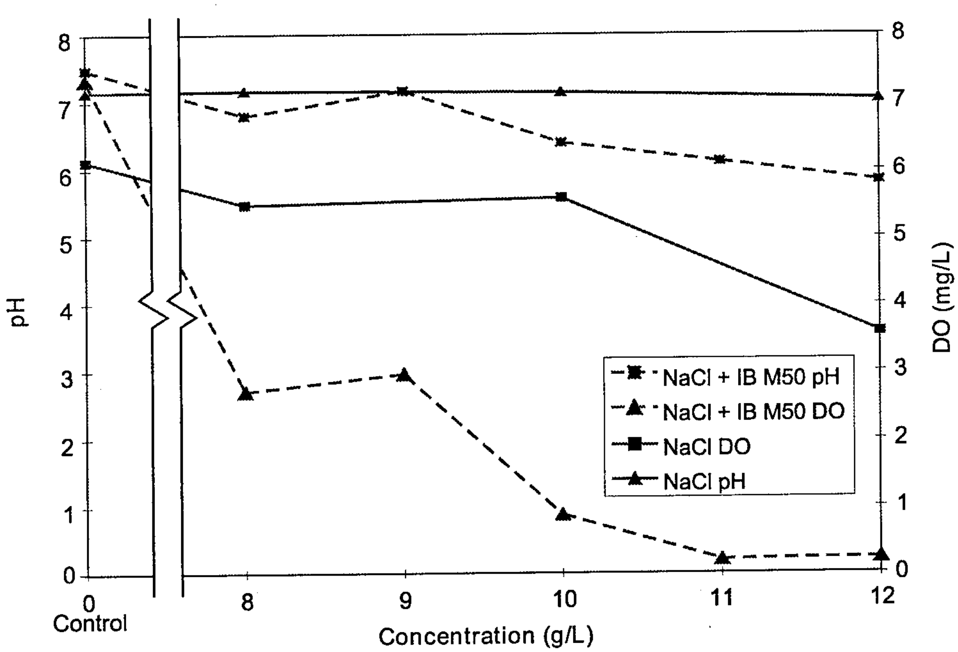

Figure 7. Final Dissolved Oxygen and pH Values with NaCl and NaCl + IB M50

the NaCl alone. Although no further investigation as to the cause of this drop was made, the drop was likely due to the biodegradation of the agricultural by-products in Ice Ban M50.

Roadside Vegetation Stress Test

Although reflectance and fluorescence were measured for each test plot, only the reflectance values were used in the analysis because of problems with the fluorescence data. Figure 8 shows the mean reflectance values for each of the 17 roadside vegetation plots. The data were highly variable because of the heterogeneous surface created by the turfgrass. To account for the resulting abnormally distributed data, only non-parametric statistical tests were used in the analysis.

Figure 9 compares the effects of many of the deicers in various concentrations. NaCl and NaCl + Ice Ban M50 caused the same level of stress when applied at the same concentration. When NaCl + Ice Ban M50 was applied at the medium or low rate (which is potentially feasible according to suggested application rates of the supposedly more effective NaCl + Ice Ban M50 combination), the stress was reduced as compared with that caused by the high concentration of NaCl. The stress caused by NaCl + Ice Ban M50 also appears to be similar to the stress caused by NaCl + $MgCl_2$ for respective concentrations. NaCl alone caused more stress to the vegetation than did the combination of NaCl and $MgCl_2$ at the same concentrations.

Figure 10 shows the roadside vegetation plots following the application of the deicers. Ice Ban M50 when applied alone and in the highest concentration caused the least amount of stress of any of the deicers. In fact, the reflectance value for the plot containing the high concentration of Ice Ban M50 was lower than that of the control. However, the plots contained a variety of grasses and although some of the species did well following the application of Ice Ban M50, others suffered complete die back.

Concentration	Deicer: Control	NaCl + $MgCl_2$	NaCl + IB M50	IB M50	$MgCl_2$	NaCl
High (9)		**0.25** (0.26)	**0.42** (0.32)	**0.15** (0.12)	**0.45** (0.28)	**0.49** (0.31)
Medium (6)	**0.20** (0.15)	**0.29** (0.35)	**0.27** (0.30)	**0.21** (0.21)	**0.31** (0.19)	**0.26** (0.23)
Low (3)	**0.22** (0.20)	**0.22** (0.13)	**0.22** (0.17)	**0.31** (0.26)	**0.25** (0.20)	**0.36** (0.38)

Figure 8. Mean *(bold)* and Standard Deviation *(in parentheses)* of Reflectance Values for Each Roadside Vegetation Plot Exposed to Deicers. Higher reflectance values indicate greater stress.

	NaCl + $MgCl_2$ (9,H)	NaCl + $MgCl_2$ (6,M)	NaCl + $MgCl_2$ (3,L)	NaCl + IB M50 (9,H)	NaCl + IB M50 (6,M)	NaCl + IB M50 (3,L)	NaCl (9,H)	NaCl (6,M)	NaCl (3,L)
Control	*	*	*	⬆	*	*	⬆	*	*
NaCl (3,L)	*	*	*	*	*	*	*	*	
NaCl (6,M)	*	*	*	*	*	*	⬆		
NaCl (9,H)	⬅	⬅	⬅	*	⬅	⬅			
NaCl + IB M50 (3,L)	*	*	*	⬆	*				
NaCl + IB M50 (6,M)	*	*	*	*					
NaCl + IB M50 (9,H)	*	*	⬅						
NaCl + $MgCl_2$ (3,L)	*	*							
NaCl + $MgCl_2$ (6,M)	*								
NaCl + $MgCl_2$ (9,H)									

* No statistical difference

Figure 9. Matrix Showing Statistical Comparison of Stress on Roadside Vegetation Caused by Deicers. Arrows point to deicer that caused more stress.

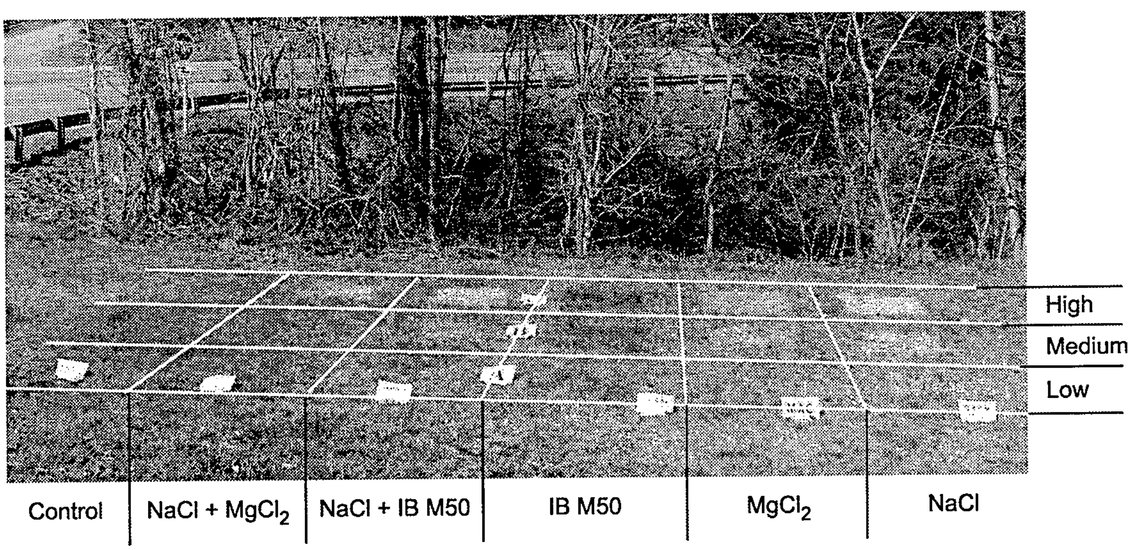

Figure 10. Roadside Vegetation Plots Approximately 6 Weeks Following Application of Deicers

Infrastructure Effects

The laboratory tests for concrete scaling and metal corrosion produced noticeable amounts of mold on the surfaces of the concrete blocks and the metal coupons where Ice Ban M50 was used. Minnesota Corn Processors, the technical advisor for Ice Ban America, Inc., analyzed a sample of VDOT's supply of Ice Ban M50. They reported that an inhibitor intended to control the growth of mold was not present in the VDOT sample as was specified in their manufacturing process. The effect this may have had on the results of our tests is unknown at this time.

Concrete Scaling

Table 5 shows the concrete scaling data. The data are sorted by deicer chemical and indicate the cumulative scale weight at 5, 10, 15, and 20 freeze-thaw cycles for each of the 12 sample blocks and the 3 control blocks.

Table 6 provides the results of the Fisher's exact probability test. Although a number of combinations of chemicals were compared, the primary aim of this study was to determine the effect of Ice Ban M50 on NaCl when used as a prewetting liquid. Statistically, there was insufficient evidence to reject the H_0 hypothesis that NaCl and NaCl prewet with Ice Ban M50 cause the same amount of scaling. The same can be said when comparing NaCl prewet with Ice Ban M50 and NaCl prewet with $MgCl_2$.

Table 5. Concrete Block Data: Cumulative Scale Weight Loss (g)

Chemical Solution	5 Cycles	10 Cycles	15 Cycles	20 Cycles
Water I	0.13	0.17	0.20	0.28
Water II	0.11	0.24	0.29	0.56
Water III	0.13	0.24	0.29	0.39
NaCl I	48.14	105.61	153.78	198.94
NaCl II	44.99	122.78	187.34	258.26
NaCl III	20.39	76.00	140.58	196.67
NaCl + $MgCl_2$ I	37.70	110.83	178.58	249.78
NaCl + $MgCl_2$ II	41.11	123.59	192.35	257.62
NaCl + $MgCl_2$ III	44.36	115.23	166.75	212.72
NaCl + IB M50 I	34.07	100.27	154.01	207.98
NaCl + IB M50 II	26.84	100.22	154.96	224.01
NaCl + IB M50 III	26.15	87.08	156.85	208.26
IB M50 I	0.42	0.73	0.92	1.13
IB M50 II	0.28	0.60	0.77	0.84
IB M50 III	0.47	0.75	0.90	1.06

Table 6. Results of Fisher's Exact Probability Test for Concrete Block Scaling

Comparison		p	Conclusion
Chemical Solution 1	Chemical Solution 2		
NaCl + IB M50	Water	0.05	Reject H_0; NaCl + IB M50 > Water
NaCl + IB M50	IB M50	0.05	Reject H_0; NaCl + IB M50 > IB M50
NaCl + IB M50	NaCl + $MgCl_2$	0.5	Insufficient evidence to reject H_0
NaCl + IB M50	NaCl	0.5	Insufficient evidence to reject H_0

> indicates the first chemical causes more scaling than the second chemical.

Table 7 shows the visual grade in accordance with ASTM C 672-91 for each set of blocks after 5, 10, 15, and 20 freeze-thaw cycles and the average cumulative scale weight loss. The visual grades are:

0 no scaling
1 very slight scaling, no coarse aggregate visible
3 moderate scaling, some coarse aggregate visible
4 moderate to severe scaling
5 severe scaling, coarse aggregate visible over entire surface.

Although the test is somewhat subjective, the results indicate that the visual grades for the NaCl, NaCl + Ice Ban M50, and NaCl + $MgCl_2$ samples were similar at the end of each review period. The same results were indicated when the visual grades for the Ice Ban M50 samples were compared with those for the control samples.

Table 7. Concrete Scaling Summary

Deicer Chemical Solution	No. of Freeze/Thaw Cycles	Visual ASTM Grade	Average Scale Cumulative Weight (g)
Water	5	0	0.12
	10	0	0.22
	15	0	0.26
	20	0	0.41
NaCl	5	4	37.84
	10	5	101.46
	15	5	160.57
	20	5	217.96
NaCl + $MgCl_2$	5	4	41.06
	10	5	116.55
	15	5	179.23
	20	5	240.04
NaCl + IB M50	5	4	29.02
	10	5	95.86
	15	5	155.27
	20	5	213.42
IB M50	5	0	0.39*
	10	0	0.69*
	15	0	0.86*
	20	0	1.01*

*The weight of scale material for the IB M50 samples was mostly from mold growing on the blocks. Little concrete scale was evident.

Corrosion of Metal

Table 8 shows the metal coupon data. The data are sorted by deicer chemical and indicate the corrected weight loss and corrosion rate at the end of the test period. Fisher's exact probability test was used to compare the data. The results are shown in Table 9.

Table 8. Metal Coupon Data

Chemical Solution (Sample No.)	Corrected Weight Loss (6 wk)	Corrosion Rate (mg/yr)	Average Corrosion Rate
Water (80)	247.2	7.4	7.3
Water (79)	305.2	9.1	
Water (78)	179.0	5.3	
NaCl (77)	2571.0	77.2	86.0
NaCl (76)	3124.1	94.0	
NaCl (75)	2891.0	86.9	
NaCl + $MgCl_2$ ((74)	1769.1	53.1	67.3
NaCl + $MgCl_2$ (73)	2391.9	71.9	
NaCl + $MgCl_2$ (72)	2564.9	77.0	
NaCl + IB M50 (71)	3073.8	92.5	103.3
NaCl + IB M50 (51)	3467.7	104.1	
NaCl + IB M50 (52)	3774.1	113.3	
IB M50 (53)	1328.4	39.9	44.9
IB M50 (54)	1855.8	55.9	
IB M50 (55)	1291.6	38.9	
Cleaning (59)	120.3		

Table 9. Results of Fisher's Exact Probability Test for Metal Coupons

Comparison			
Chemical Solution 1	**Chemical Solution 2**	***p***	**Conclusion**
NaCl + IB M50	Water	0.05	Reject H_0; NaCl + IB M50 > Water
NaCl + IB M50	IB M50	0.05	Reject H_0; NaCl + IB M50 > IB M50
NaCl + IB M50	NaCl + $MgCl_2$	0.05	Reject H_0; NaCl + IB M50 > NaCl + $MgCl_2$
NaCl + IB M50	NaCl	0.5	Insufficient evidence to reject H_0

> indicates the first chemical solution causes more corrosion than the second chemical solution.

CONCLUSIONS

- The composition of Ice Ban M50 changes from batch to batch and over time.
- The studies reviewed indicate that Ice Ban M50 applied directly to the pavement at low temperatures can provide an improved level of service as compared to similar quantities of liquid $MgCl_2$, NaCl only, or prewetted NaCl.
- No study reviewed indicates NaCl prewet with Ice Ban M50 is less expensive than NaCl prewet with another chemical.

- No study reviewed indicates Ice Ban M50 is less expensive than other liquids applied directly to the pavement.

- When used as a prewetting liquid, Ice Ban M50 has no impact on the effect of NaCl on turfgrass germination, freshwater minnow mortality rate, or roadside vegetation stress.

- When used alone, Ice Ban M50 is less stressful to roadside vegetation than any other chemical tested.

- When used as a prewetting liquid, Ice Ban M50 has no impact on the effect of NaCl on concrete scaling or metal corrosion.

- When used alone, Ice Ban M50 is less corrosive to metal and causes less scaling of concrete than any other chemical tested. The single exception may be the effect on metal of NaCl prewet with $MgCl_2$ because the comparison was inconclusive.

RECOMMENDATIONS

1. *VDOT should not use Ice Ban M50 as a prewetting agent for NaCl.* Ice Ban M50 used as a prewetting agent showed no appreciable infrastructure or environmental benefits. The cost and operational problems (as determined from the literature reviewed) involved with using Ice Ban M50 exceeded those of other chemicals used in prewetting operations.

2. *VDOT should consider further experimentation using Ice Ban M50 applied directly to pavements in situations where temperatures are below -12 °C.* Experimentation should proceed cautiously until additional research addresses concerns with product stability, mold, and other probable environmental issues.

ACKNOWLEDGMENTS

The authors thank the personnel of VDOT's Warrenton Residency, the Marshall Maintenance Area Headquarters, and the Phoenix Development Corporation for their assistance with the field testing portion of this study. Dr. Arnold F. Theisen of the Virginia Institute of Marine Science assisted with the collection and interpretation of data gathered for the roadside vegetation stress test. The chemistry lab in VDOT's Materials Division, under the direction of Wendy Ealding and with the assistance of E.C. "Betsy" Mack, was responsible for the testing of concrete scaling and metal corrosion.

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